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RELATED PCT APPLICATION NUMBER: *PCT/US03/23043*

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Attorney Docket No. 00807-01

U.S. DEPARTMENT OF COMMERCE
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PROVISIONAL APPLICATION FOR PATENT COVER SHEET

Certificate Under 37 CFR 1.10
Date of Deposit: July 25, 2002
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Sue Ann Carr
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JC879 U.S. PTO 60/398373

Address to: Box Provisional Application
Assistant Commissioner for Patents
Washington, DC 20231
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This is a request for filing a Provisional Application for Patent under 37 CFR 1.53(c)

Inventor(s) and Residence(s) (city and either state or foreign country):

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For: CELLULAR MATERIALS AND STRUCTURES FOR BLAST AND IMPACT MITIGATION IN STRUCTURES AND RELATED METHOD AND SYSTEM

7 Sheets of specification.
Sheets of drawings.

University of Virginia Patent Foundation claims small entity status as a nonprofit organization (37 CFR §1.9(e) and §1.27(d)). Therefore, please charge the Small Entity Fee of **$80** to **Deposit Account No. 50-0423.**

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This invention was made by an agency of the United States Government or under a contract with an agency of the United States Government. The government has certain rights in the invention.

YES ☒ NO ☐ Grant No. ONR N00014-01-1-1051

Dated: July 25, 2002

Respectfully submitted,

By:
Robert J. Decker (Reg. No. 44,056)

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Cellular Materials and Structures for Blast and Impact Mitigation in Structures and related Method and System

BACKGROUND OF THE INVENTION

The design of structures has yet to exploit emerging capabilities of cellular materials for blast and impact energy absorption. Dramatic improvements can be made in the design of structures to either absorb or reflect blast energy by exploiting recent progress in cellular materials, fabrication and optimization. The approach utilizes sandwich panels containing core materials topologically structured at small scale, relative to a system (e.g. ship hull) that utilize them. They are optimized to absorb or reflect the energy subject to their ability to support high structural loads. It is compatible with double-hull concepts, because the volume between the hulls is used to locate the energy absorbing material substructures.

The technology to design such a structure requires materials and cell topology design and techniques for the manufacturing of structures that must be able to sustain severe dynamic deformations. It requires *coupling* of effects occurring at the materials and structural levels. Implementation requires advances in the fabrication of topologically constructed panels which is also disclosed here.

BRIEF SUMMARY OF INVENTION

The topological choices for the core material of a sandwich panel, energy absorbing system will comprise periodic designs, based on corrosion resistant metals such as stainless steels and titanium alloys and other materials (including polymers, ceramics and composites) formed into hollow spheres, truncated cones, corrugations and trusses. These can be placed within large boxes of polygonal cross section or arrays of circular or elliptical cross section tubes and bonded to face sheets, **Fig. 1**. Stochastic foam core systems can also be used but frequently have inferior mechanical (and, in some cases, inadequate corrosion) capabilities. These systems can out perform the existing concepts which are cellular materials within an ensemble of hollow bonded tubes or a hexagonal honeycomb. The cores are spray coated with transient liquid phase precursors, face sheets are superposed and the lay-up heated to create bonding. This approach

can be used to create wide panels (many meters) with cores having a range of thickness. Corrosion resistant steels for naval applications are feasible. In the case of some metal systems, subsequent quenching and tempering can be used to manipulate the strength and strain hardening characteristics. Super plastic forming/diffusion can be used to create analogous structures from titanium alloys.

Hollow, space filling three-dimensional arrays of square and triangular boxes can be constructed from sheet and bonded by transient liquid phases, **Fig. 1**. Similar bonding can be used to create sheets of hollow tube arrays and spheres. These can be placed between face sheets and used to create structures with large energy absorption to maximize the number of plastic buckles per unit length. Variables include the cross sectional shape, the aspect ratio and wall thickness of the box/tubes and the topology of the cellular materials within.

Recent assessments have highlighted the potential for conical configurations to achieve large energy absorption, **Fig. 1**. As these cores compress, a plastic knuckle initiates at the apex and propagates toward the base. This process allows all material elements in the core to experience large-scale plastic strains. These cores have low relative density, in the 1-5% range (figure 3). Panels can be made by using rolling and CNC bending techniques to create core structures and exploiting transient liquid phase (TLP) bonding to attach the faces. This approach has the attributes of low cost, uniform cells, many materials choices, mechanical properties representative of wrought metals, and a capability to manufacture in large size.

Truss core topologies are highly applicable, **Fig. 2**. The structural performance of cores consisting of tetrahedral, pyramidal and Kagome trusses have been shown to result in minimum weight designs superior to hexagonal honeycombs [1]. Cores will be fabricated using metal stamping and CNC bending processes to create three or four sided core structures with apices oriented perpendicular to the plane. The cores of this type can be built into panels using the TLP and diffusion bonding methods noted above, then attached to rigid supports and tested to determine the overall load/deflection response prior to face tearing.

The large interior spaces within constructed hollow boxes and tubes provide novel opportunities for additional energy absorption. Several ideas are shown in **Fig. 3**. It is also possible to inexpensively place three and four legged trusses or their closed cell analogs (tetrahedral and pyramids) in boxes and triangular tube arrays and add hollow powder. These ideas are illustrative of hierarchical concepts that dynamic impact/blast loading and efficiency of

static load support.

BRIEF SUMMARY OF THE DRAWINGS

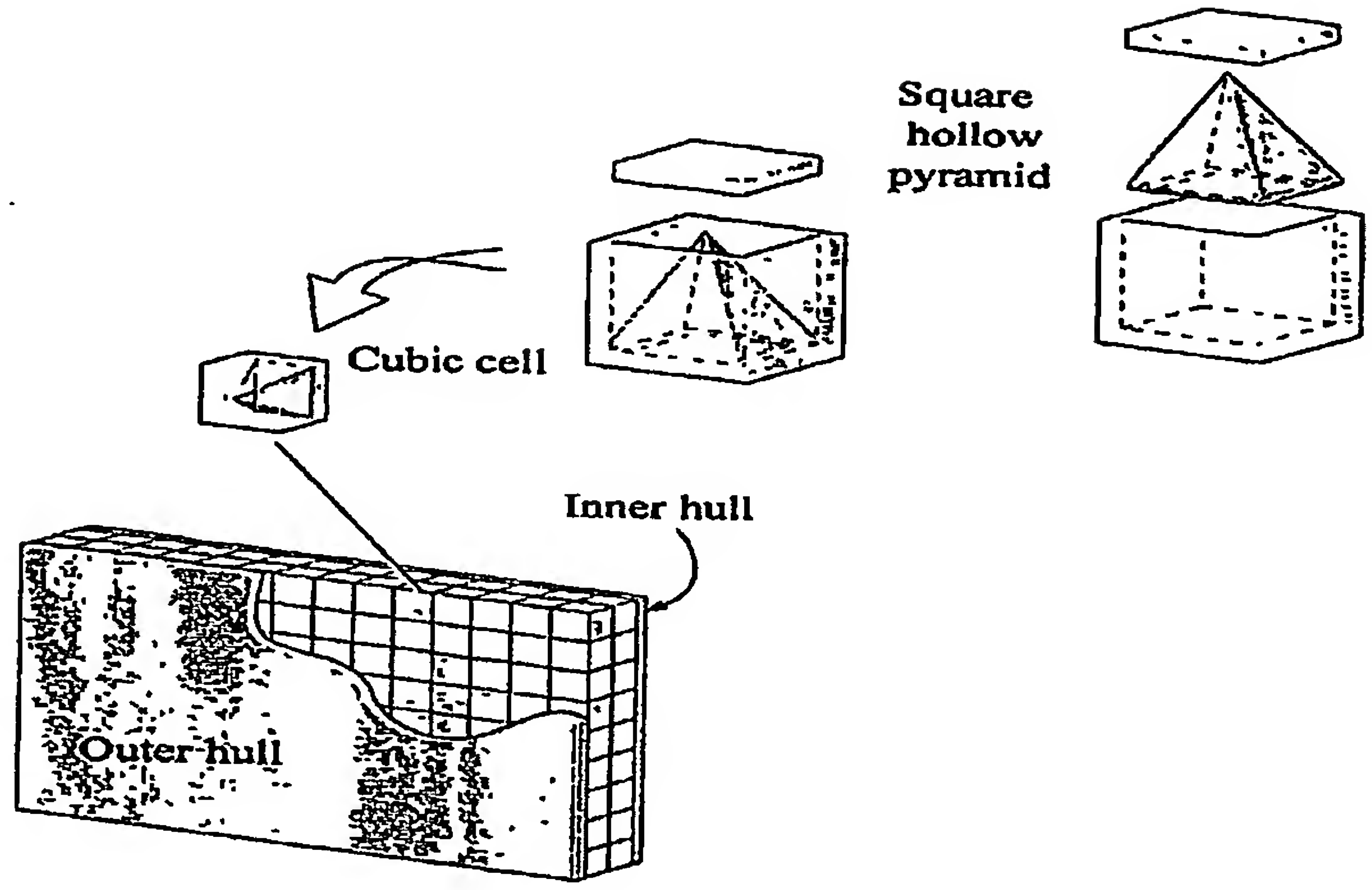

Figure 1. A concept for impact on blast energy absorption utilization periodic cellular metal structures made from corrosion resistant alloys. In this case these water buoyant materials are used for the double hull of ship.

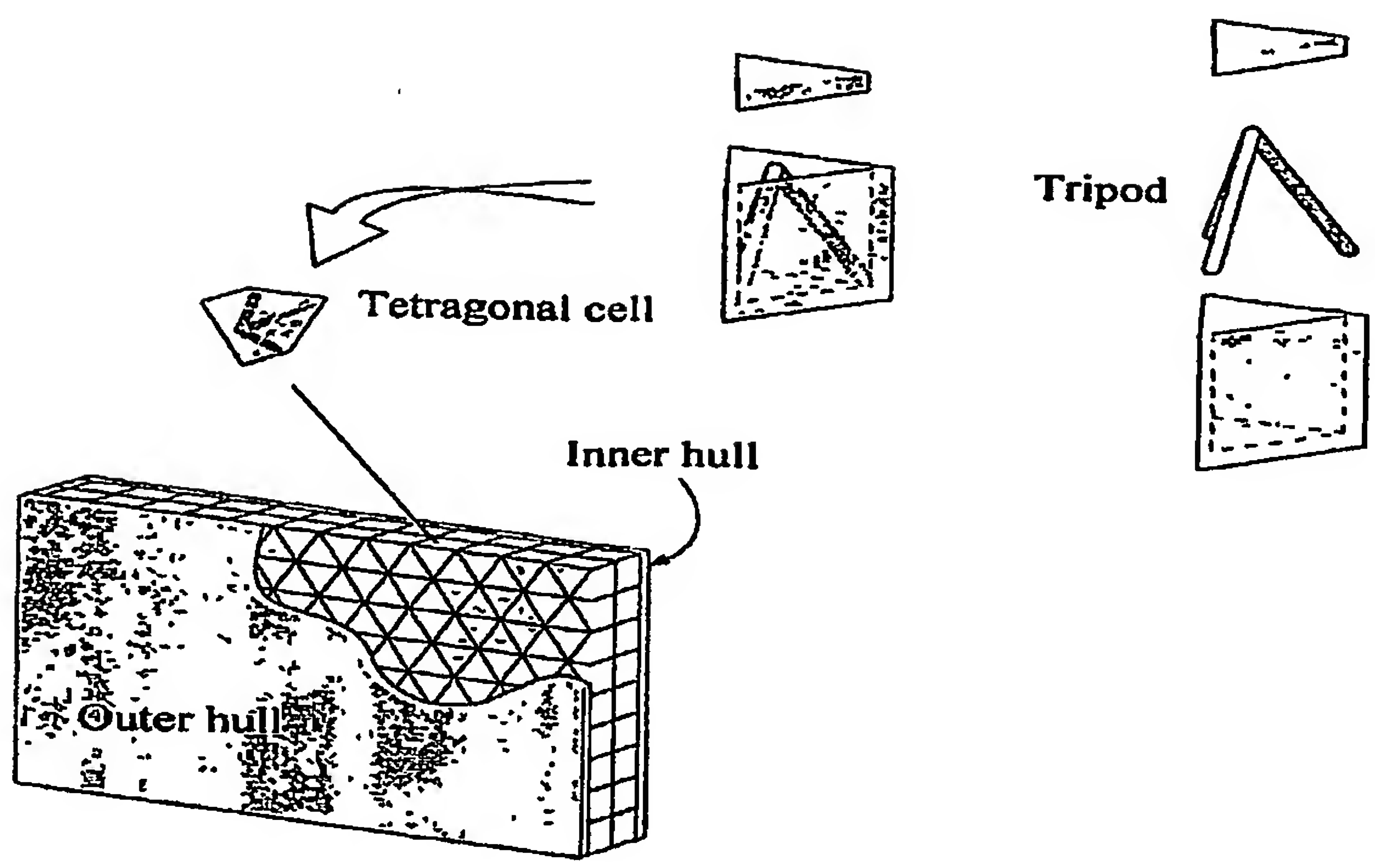

Figure 2. Truss core concepts can be used to create structurally efficient high-energy absorption structures.

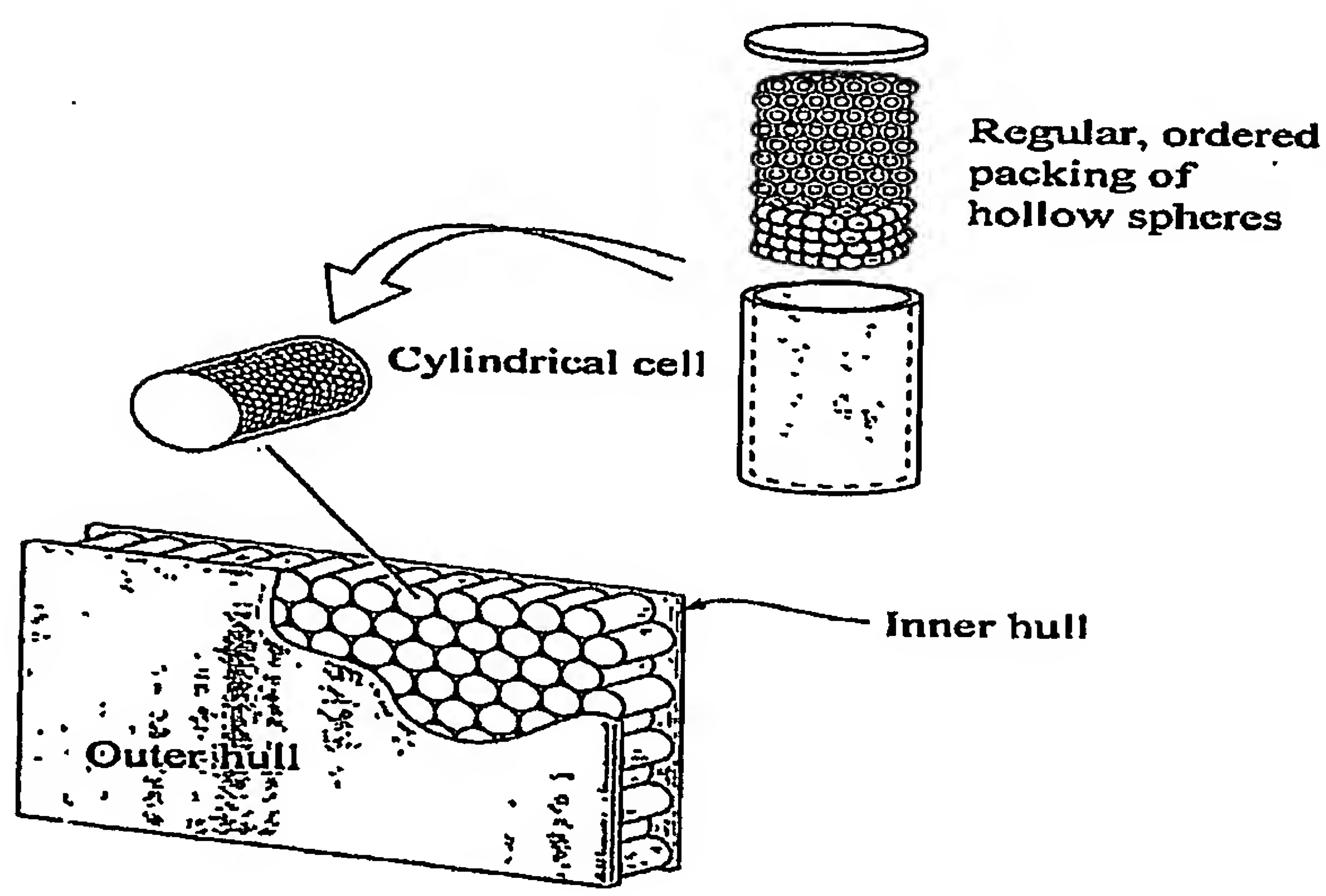

Figure 3. Hierarchical energy absorbing structures utilizing hollow powder filled tubes. The hollow powder is weakly bonded and interacts with the tubs to increase the buckling spatial frequency. Additional energy is absorbed by powder friction and plastic compression of the powder.

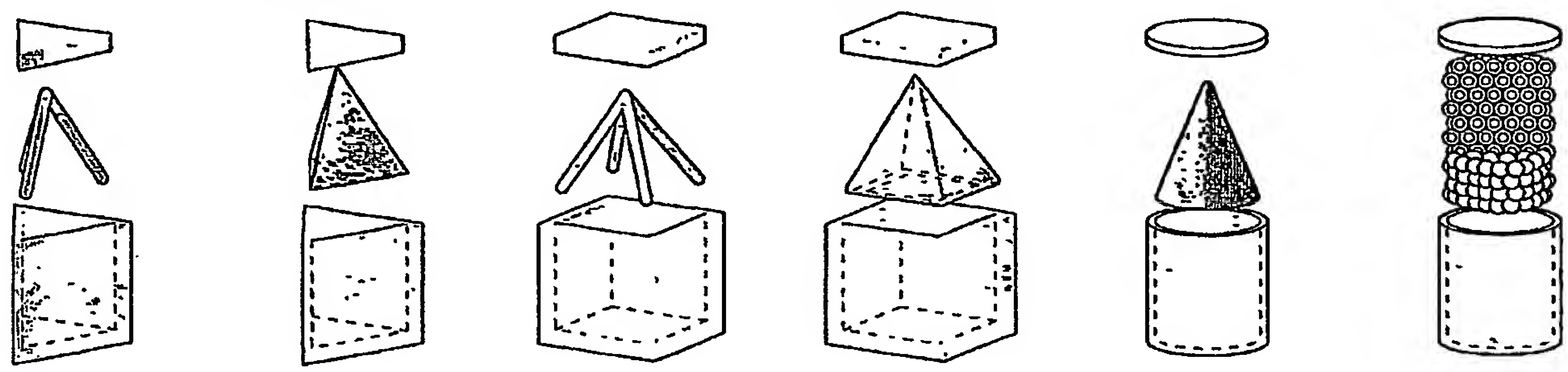

Figure 4. Examples of exemplary of hierarchical energy mitigating cone concepts.

DETAILED DESCRIPTION OF THE INVENTION

The energy absorption of a porous structure subject to severe impact loading is governed by the extent of its plastic deformation. When high strain shape change of the internal topology by plasticity (as opposed to bending), as the volume of plastically deformed material and its strain are increased, the energy absorbed increases. Further increases occur by heating (increased by the selection of the system heat capacity) and frictional dissipation. In conjunction with the fabrication approaches described below, these principles enable creation of novel topological concepts that maximize the absorption of mechanical impulses from impacts and blasts. These include hierarchical concepts involving structures with numerous length scales and sequential energy absorption activation pressures. Examples include tube arrays containing hollow metal powder, or cubic box arrays containing cones or pyramids inside of which is placed granular materials for frictional dissipation and plastic compaction.

The present invention provides a basis for designing and manufacturing core topologies and panel designs in accordance with two different scenarios: one for high intensity and the other for moderate impacts and blasts. The former establish rules for the design of cores and faces with strength sufficient to reflect the incident impulse or its absorption by plasticity. The latter create designs that allow the maximum energy absorption per unit mass by various dissipation

mechanisms associated with deformation of the cone.

Flexible, low cost approaches the bonding of metallic sub assemblies (trusses, hollow sphere, tubes, with face sheets) of different materials including metallic alloys can be fabricated. For metals, the techniques include the use of transient liquid phases and diffusion bonding. Other methods such as electric discharge welding of contacts and adhesive bonding can also be used. Adhesives can be used for other materials.

Many methods for scalable fabrication of periodic core structures with precisely controlled topologies exist or can be devised. Methods for metals include sheet perforation, CNC bending, roll forming, hot isothermal forging, super plastic deformation, powder injection molding and various casting concepts. Each method has advantages and disadvantages for the alloy systems of interest (e.g. stainless steels, aluminum, copper, nickel and titanium alloys). These cellular structures can be placed within a cellular array with cubic, triangular or other polygonal cross section as well as arrays of tubes.

PUBLICATIONS

The following publications and patent applications are hereby incorporated by reference herein in their entirety:

- "Cellular Metals Manufacturing: An Overview of Stochastic and Periodic Concepts", H.N.G. Wadley, Met Foam 2001 Conference Proceedings, pp. 137-146, 2001.
- "Cellular Metal Truss Core Sandwich Structures", D. J. Sypeck and H.N.G. Wadley, Met Foam 2001 Conference Proceedings, pp. 381-386, 2001.
- " The Structural Performance of Near-Optimized Truss Core Panels", S. Chiras, D.R. Mumm, A.G. Evans, N. Wicks, J.W. Hutchinson, S. Fichter, K. Dharmasena, and H.N.G. Wadley, *International Journal of Solids and Structures*, In Press, Jan. '02.
- "On the Performance of Light Weight Metallic Panels Fabricated Using Textile Technology", D.R. Mumm, S. Chiras, A.G. Evans, J.W. Hutchinson, D.J. Sypeck, and H.N.G. Wadley, *International Journal of Mechanical Sciences*, submitted Aug. '01.
- "Cellular Metals Manufacturing", H.N.G. Wadley, Metfoam Issue of Advanced Engineering Materials, submitted Mar. 2002.
- PCT International Application No. PCT/US01/17363, entitled "Multifunctional Periodic

Cellular Solids And The Method Of Making Thereof," filed on May 29, 2001

- PCT International Application No. PCT/US02/17942, entitled "Multifunctional Periodic Cellular Solids And The Method Of Making Thereof," filed on June 6, 2002 (Attorney Docket No. 00683-02)

Executive Summary

The present invention provides, among other things, multifunctional sandwich panels containing topologically optimized cellular cores for efficient load support and blast/impact protection are provided, as well as related methods of making the same. They are based upon a hierarchical concept in which the interior space between face sheets is segmented into a closed cell structure. Cells can be of triangular, square and other polygonal cross sections as well as arrays of tubes. The interior of these structures are then filled with cellular structures of either a periodic (e.g. truss, polyhedral or hollow sphere) form. These unit cells can be arranged in a multiplicity of orientations. These structures can be made from a variety of materials (metals, polymers, ceramics, and composites involving mixtures of each material. Simple methods for the manufacturer of these structures is also incorporated in the invention.

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[1] "Cellular Metals Manufacturing: An Overview of Stochastic and Periodic Concepts", H.N.G. Wadley, Met Foam 2001 Conference Proceedings, pp. 137-146, 2001.

"Cellular Metal Truss Core Sandwich Structures", D. J. Sypeck and H.N.G. Wadley, Met Foam 2001 Conference Proceedings, pp. 381-386, 2001.

" The Structural Performance of Near-Optmized Truss Core Panels", S. Chiras, D.R. Mumm, A.G. Evans, N. Wicks, J.W. Hutchinson, S. Fichter, K. Dharmasena, and H.N.G. Wadley, *International Journal of Solids and Structures*, In Press, Jan. '02.

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